Enhancing weather radar winter precipitation accumulation estimates

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Abstract Snowfall estimates for weekly, monthly, and seasonal accumulation periods have been compared to measured Nipher-shielded Belfort precipitation gauge quantities. A local scaling issue that caused overestimates is discussed. To enhance the accumulation estimates, the conventional scan radar images were adjusted using the near surface air temperatures. The adjustment for mixed precipitation improved the accumulation estimates, while the subsequent particle shape adjustment for snow crystal shape did not further enhance the radar estimates.

Key words mixed precipitation; precipitation measurement; radar; rainfall; snowfall

INTRODUCTION

Ground based weather radar is often used to estimate precipitation since it can provide rainfall maps that are not readily made from gauge data. Radar-precipitation research has focused on refinement of the coefficients for snowfall by investigation of reflectivity, precipitation rates and precipitation particle properties. Current approaches use the advanced capabilities of radar to examine more discrete precipitation properties. Investigations have often been limited to individual storm events, and only Fassnacht *et al.* (1998) have illustrated the comparison of gauge to radar for snowfall accumulations of long periods. This study compares the seasonal, monthly and weekly accumulations of snow, as measured by precipitation gauges, to the snowfall estimates derived from ground-based weather radar. Such data can be valuable input to distributed hydrological models (Fassnacht *et al.*, 1998). The radar images are adjusted to consider variations in the precipitation phase and shape.

STUDY SITE

The radar operated by the Meteorological Service of Canada (MSC) near King City, Ontario, is a C-band installation ($\lambda = 5.2$ cm), and has a conventional mode coverage of 200 km. The Richards & Crozier (1983) and Sekhon & Srivastava (1970) *Z-R* coefficients are used for summer and winter seasons. The radar images used in this study are precipitation accumulations in mm h^{-1} for a 2×2 km pixel. The snowfall accumulations were measured using Belfort precipitation gauges with Nipher shields.

The gauges were located in a "bush" type setting. The wind under-catch of such gauges is minimal. The three precipitation gauges collected data for up to five years.

METHODOLOGY

The discretization of the precipitation rates and the storage of the radar data at times yielded a local scaling problem, which caused an overestimation as a result of forced over-scaling due in part to anomalous propagation. To overcome the forced over-scaling, the radar data was reprocessed using only the lowest increment.

Various relationships between temperature and the probability of snow have illustrated the variation in the spatial and temporal distribution of mixed precipitation. These include the Sierra Nevada (US Army Corps of Engineers, 1956), the Swiss Alps (Rohrer, 1989), and an average of 1000 observations across the United States (Auer, 1974). Precipitation underestimation can occur if the cold season *Z-R* relationship is used for rainfall or mixed precipitation. With the assumption of the same return signal and precipitation rate, the summer *Z-R* coefficients are 4.06 times larger than the winter coefficients. However, the authors have found that for hydrological modelling, radar rainfall, as provided by the King City radar, is often overestimated by a factor of two. This coefficient ratio of 2.03 was used for 100% rain from the winter *Z-R*. Using the Auer (1974) probability of snow versus temperature curve, and assuming a linear relationship between temperature and the coefficient ratio, the radar images were adjusted as per Fig. 1 (Fassnacht *et al.*, 1999).
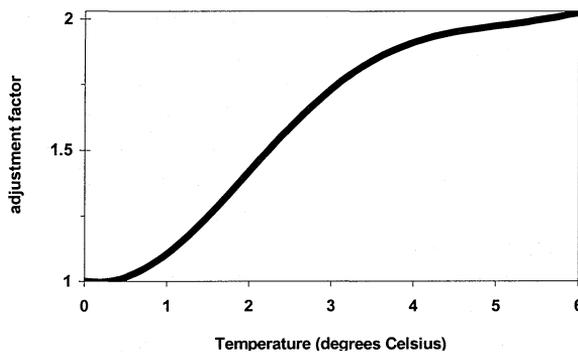

Fig. 1 The mixed precipitation adjustment curve (Auer, 1974), used to adjust radar images at warmer than freezing temperatures.

Different temperatures cause different shapes of hexagonal ice crystals to form within clouds. Ice crystals grow hexagonally in two dimensions and linearly in the third due to the matrix structure of ice molecules. Ice crystal growth between 0°C and −3°C, and between −10°C and −21°C, results in hexagonal plates or planar crystals. Columnar or needle crystals grow between −5 to −9°C and possibly below −25°C. While Ohtake & Hemni (1970) developed different *Z-R* relationships for various snowflake shapes, application of their coefficients requires knowledge of the falling crystal type. Winter lapse rates are uncertain for the study area. However, Schaefer &

Day (1981) assume that they may be small and constant throughout the winter. Since crystal shapes are a function of the formation temperature, a relationship was developed between reflectivity variations and air temperature. For a specific reflectivity, a snow crystal with a larger specific surface area will have less mass than a snow crystal with a smaller surface area. Ice crystal growth rate as a function of formation temperature has been transformed by Fassnacht et al. (1999) to yield a particle shape adjustment relationship that defines a relative surface area for different snow crystal shapes, based on temperature. Inverting this relationship to consider reflectivity variations yielded the adjustment factor curve (Fig. 2).
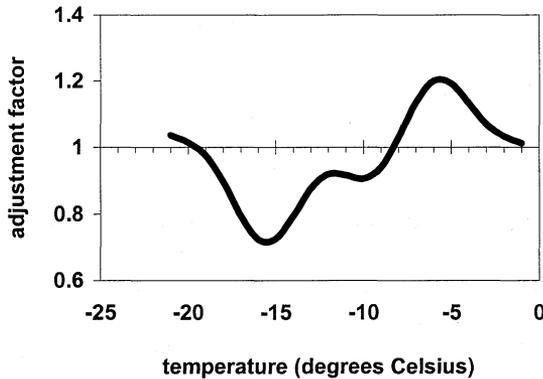

Fig. 2 The particle shape adjustment curve used to adjust the radar images at colder than freezing temperatures.

RESULTS

The seasonal standard error of estimate (*SEE*) is similar for all adjustment procedures, yet r^2 values vary substantially (Table 1). The seasonal and monthly statistics show the same trend, especially for the mean difference. However, there is significantly more scatter. For weekly accumulations, there is more scatter with the temperature adjusted radar estimates than for the "scaling removed" estimate. However, the underestimates are improved using mixed precipitation adjustment.

Table 1 Regression statistics for the different accumulation length comparisons using raw radar and various adjustment schemes. Statistics are weighted by record length. The mean difference (*diff*) and standard error of estimate (*SEE*) are in mm day^{-1}. The determination coefficient is r^2.

Adjustment method	Seasonal (*n* = 8)			Monthly (*n* = 27)			Weekly (*n* = 103)		
	diff	*SEE*	r^2	*diff*	*SEE*	r^2	*diff*	*SEE*	r^2
Raw data	0.16	1.23	0.178	0.12	1.46	0.089	0.16	2.82	0.081
Minimum scaling used	−0.33	0.72	0.335	−0.34	0.87	0.272	−0.32	1.69	−0.008
Mixed precipitation	0.18	0.62	0.595	0.16	0.87	0.470	0.18	1.88	0.326
Mixed precipitation + particle shape	0.21	0.63	0.593	0.19	0.88	0.472	0.21	1.87	0.341

DISCUSSION

Removal of scaling results in an underestimation of the radar accumulation estimates. Consideration of mixed precipitation increases the underestimates and yields enhanced precipitation accumulations. Further adjustment of the radar images to consider the shape of snow crystals does not provide additional improvement to the radar precipitation accumulations.

The adjustment of the radar images for above freezing temperatures considers the radar signal variability caused by mixed precipitation. The rain factor also corresponds to the ratio of the reflectivity of water to ice. In nature, the change in temperature and the variation in particle characteristics during periods of transitional precipitation are quite rapid. Future research must consider the sub-hourly and spatial variations of mixed precipitation.

Particle shape is a difficult parameter to estimate, especially considering the size of an individual particle in comparison to the quantity of snowflakes scanned by a radar swath or captured by a gauge. The lapse rate for individual storm events and during events and the short-term variability in the snow crystal shape must be further considered. In addition, riming, aggregation, and sublimation that can alter the shape and surface area of falling snow can occur above and below a radar beam. Future research needs to quantify the particle shape curve based on specific surface area estimates of different snowflakes, as well as their relationship with temperature. The work of Ohtake & Henmi (1970) can be expanded to develop *Z-R* relationships for different temperatures and include observations of particle shape.

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